US Regional Update

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2015 International Workshop on EUV Lithography, June 15-19, Maui, Hawaii

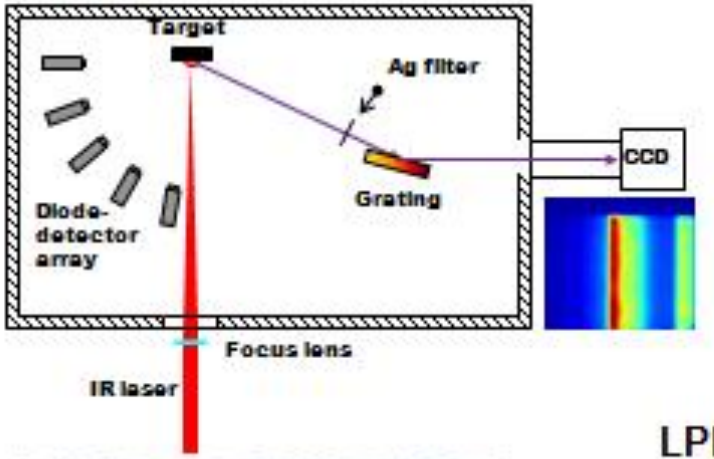
Source

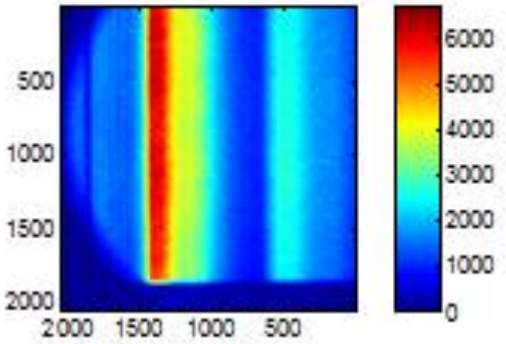
- Cymer/ASML- LPP (8:40 Thu)
- Energetiq- DPP (10:20 Thu)
- Plex- DPP
- Colorado State- X-ray/EUV laser
- CU Boulder- HHG (4:10 Thu)
- Argonne, Berkeley, Fermilab, SLAC,…- FEL (1:00 Thu)
- Jlab- FEL
- SLAC, UCLA- Alt. accelerator sources (1:40 Thu, 2:00 Thu)
- Global Foundries- FEL requirements studies

Conversion efficiency and spectral emission of laser produced Gd plasmas near λ = 6.7nm

Colorado State University

Experimental setup





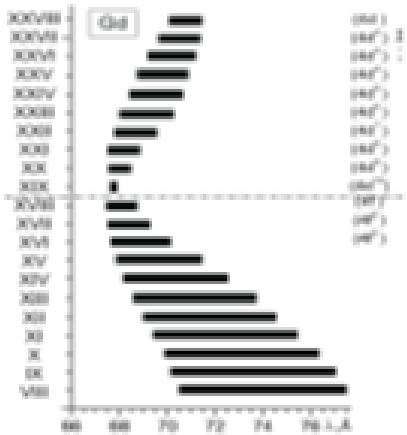
LPP produced with λ= 1.03 μm laser

- Diode array detector measures angular distribution of emission
- Grating spectrometer records spectral distribution

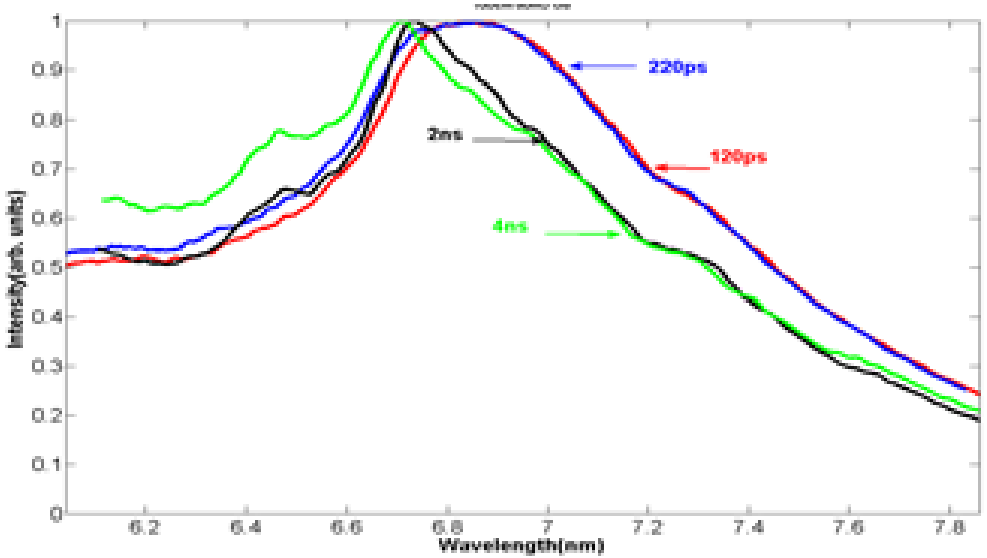
Gd spectral measurements

- Emission spectra broadens as pulse width is reduced from 2-4 ns to 0.1-0.2 ns
- Emission shifts to longer wavelengths as pulse width is reduced

Gd



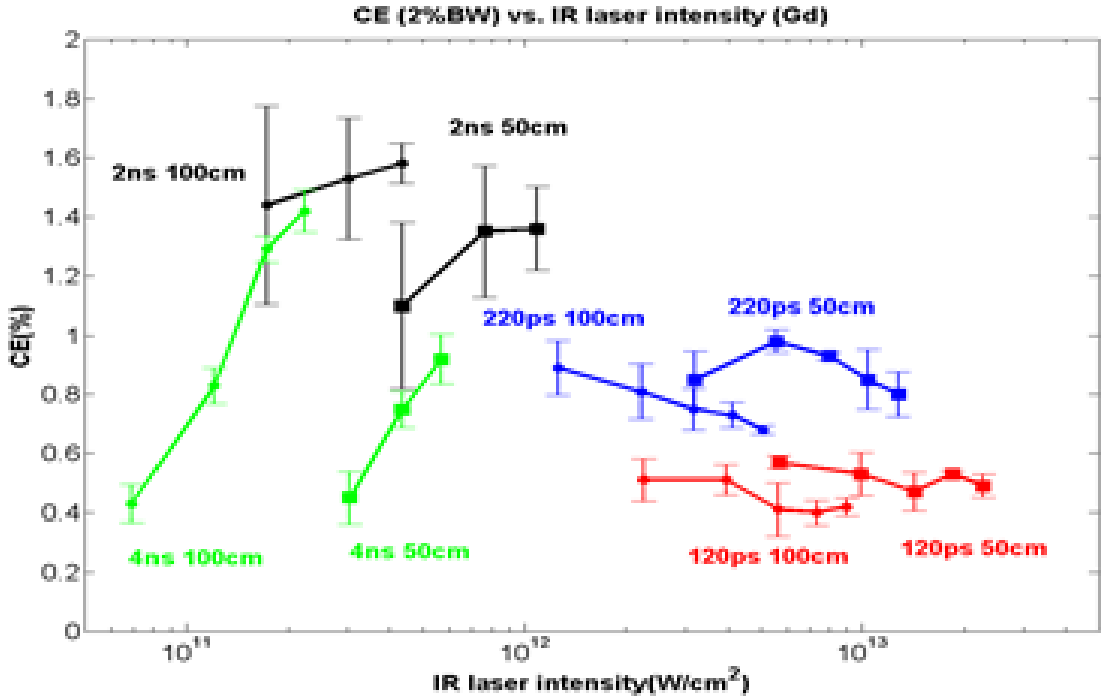
S S Churilov, et al, Phys. Scr. 80 045303 (2009)



Observed spectra compatible with ionization degree increasing towards Gd XIX

Conversion efficiency vs intensity for different laser pulse widths

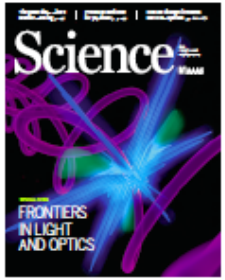
Gd plasma: spot size 50μm (f= 500 cm) and 25μm (f=100cm)



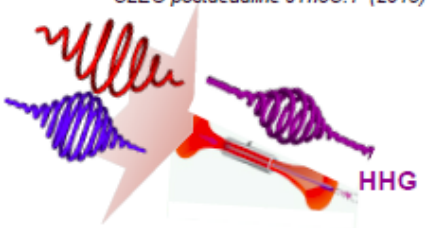
Conversion efficiency is largest for ns laser pulses

Exquisite control over X-ray light by manipulating radiating electron using laser light

- Supercontinuum or isolated peaks
- Full spatial coherence to keV
- Femtosecond to Attosecond pulses
- Linear or circular polarization
- Unique new light source better than we dreamed of!

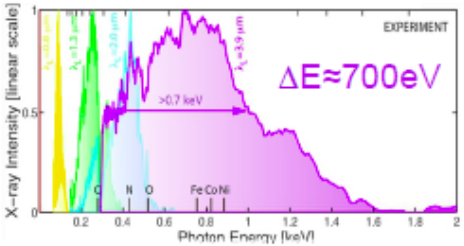


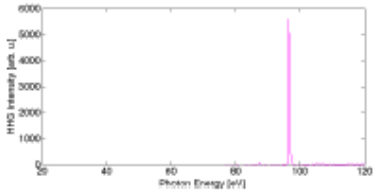
Nature Photonics **9**, 99 (2015)
CLEO postdeadline JTh5C.1 (2015)



Linear/circular polarization

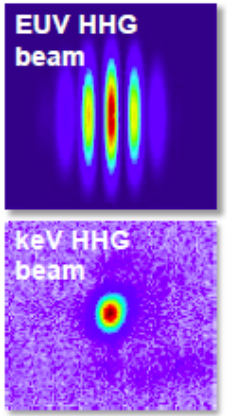
Broad coherent continuum OR Isolated single harmonic





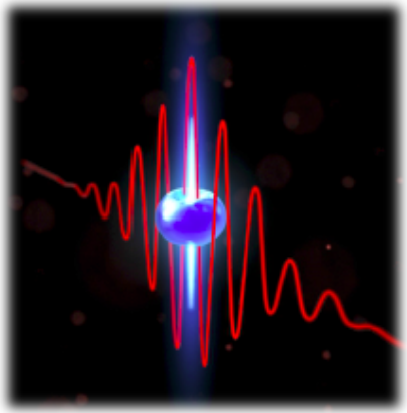
Science **336**, 1287 (2012); *CLEO postdeadline* FTh5A (2014)

Full spatial coherence: UV to soft X-ray



Science **297**, 376 (2002)
Science **348**, 530 (2015)

Femtosecond to attosec pulses: UV to soft X-ray

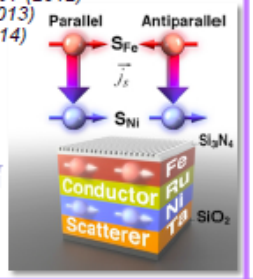


PRL **111**, 033002 (2013)
PNAS **111**, E2361 (2014)

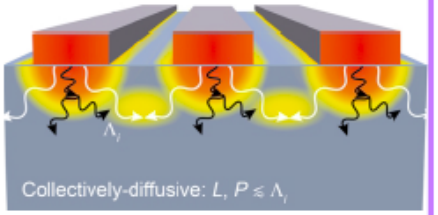
HHG uncovering new materials behavior – good access

Controlling magnetic state via fast spin dynamics

*PNAS **109**, 4792 (2012)*
*Nature Comm. **3**, 1037 (2012)*
*PRL **110**, 197201 (2013)*
arXiv:1401.4101 (2014)

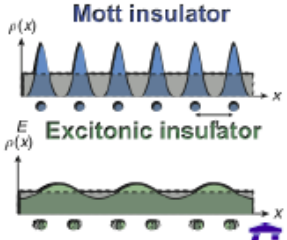


Controlling nanoscale energy transport



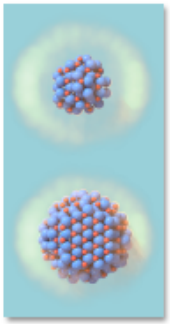
*Nature Mater. **9**, 26 (2010)*
*PNAS **112**, 4846 (2015)*

Angle-Resolved Photoemission (ARPES)

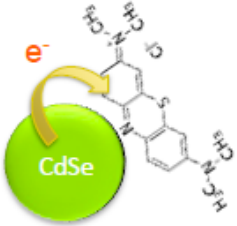


*Nature **471**, 490 (2011)*
*Nature Comm **3**, 1069 (2012)*
*PRL **112** , 207001 (2014)*

Nano, energy science

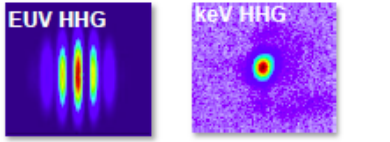


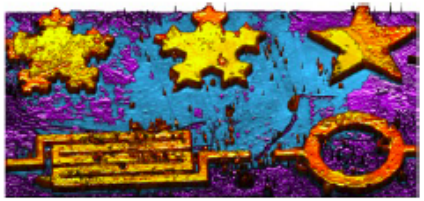
Coupling to environment, charge flow



*Nano Lett. **13**, 2924 (2013)*
*JACS **137**, 3759 (2015)*

Imaging at the λ limit





*Optica **1**, 39 (2014); Science **348**, 530 (2015)*

Commercial systems

www.kmlabs.com

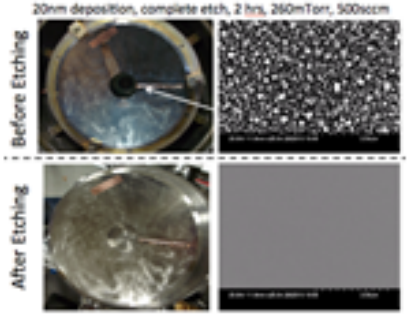
Optics

- UI Urbana-Champaign- Collector cleaning (11:00 Wed)
- Rigaku- Multilayers (10:20 Wed)
- Berkeley Lab- Multilayers
- LLNL- Multilayers
- NIST- Optics contamination (10:40 Wed)
- CNSE- Optics contamination
- Zygo- High NA optics

In-Situ Plasma Cleaning of EUV Collector

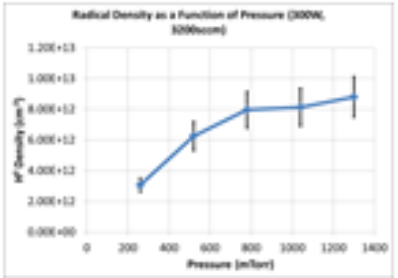
Accomplishments during 2014-2015

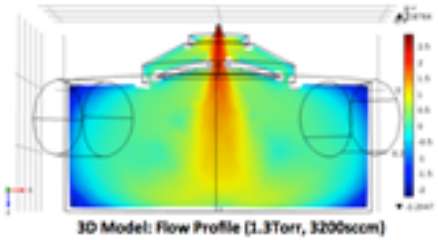
- Illinois is conducting fundamental research to gain insight into H-radical plasma cleaning of EUV collector and feasibility of this technology for in-situ implementation
- Preliminary experiments conducted to measure etch rates as a function of flow and pressure
- Dummy collector cleaning demonstrated at source operating pressure
- Hydrogen radical density measurement accomplished



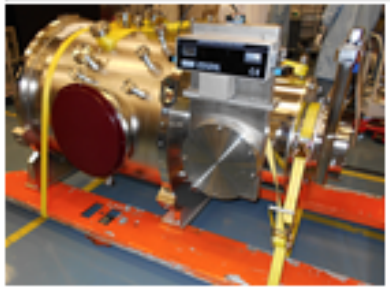
Current effort:

- Working towards establishing a predictive 3-D modeling for etch rate determination as a function of changing parameters, such as, pressure, temperature, radical density, geometry, flow path and deposition/re-deposition probabilities.
- Experiments are being set-up to obtain parameters towards the development of 3-D model



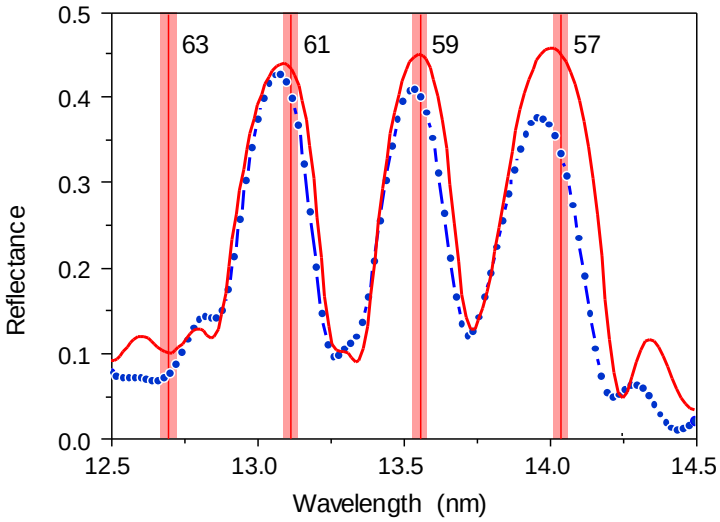


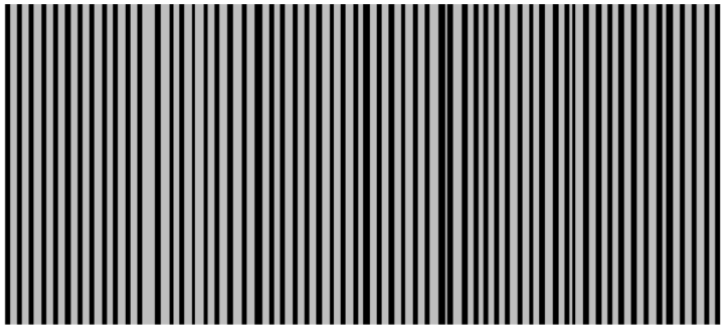
Cymer's 3100 source vessel is at Illinois at the Applied Research Institute. Industrial solution for tin cleaning is being researched.



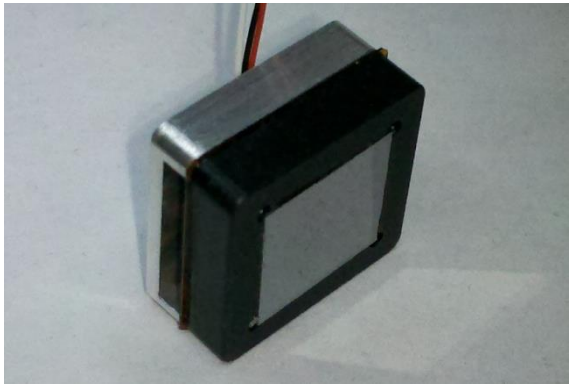
Acknowledgements:

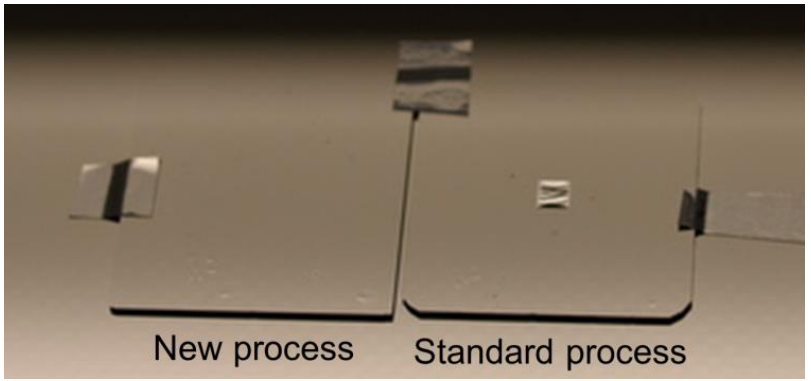
Multi-harmonic optics





Wavefront preserving EUV beamsplitters



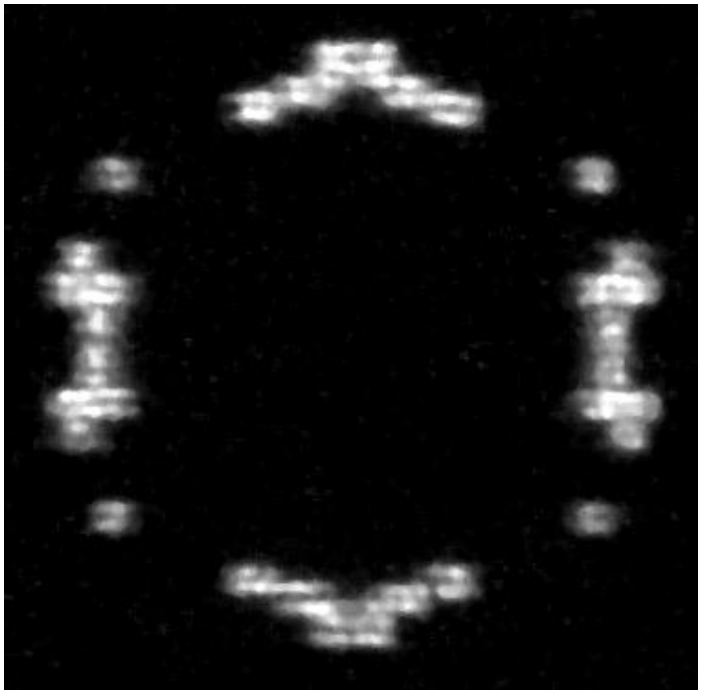


Mask

- KLA- Patterned mask inspection (3:20 Thu)
- Berkeley Lab- High NA AIMS
- Berkeley Lab- Scatterometry/roughness (4:20 Thu)
- Photronics- Mask process
- Intel- Mask process (8:50 Wed)
- SEMATECH- Mask defects
- EUV Tech- Reflectometry

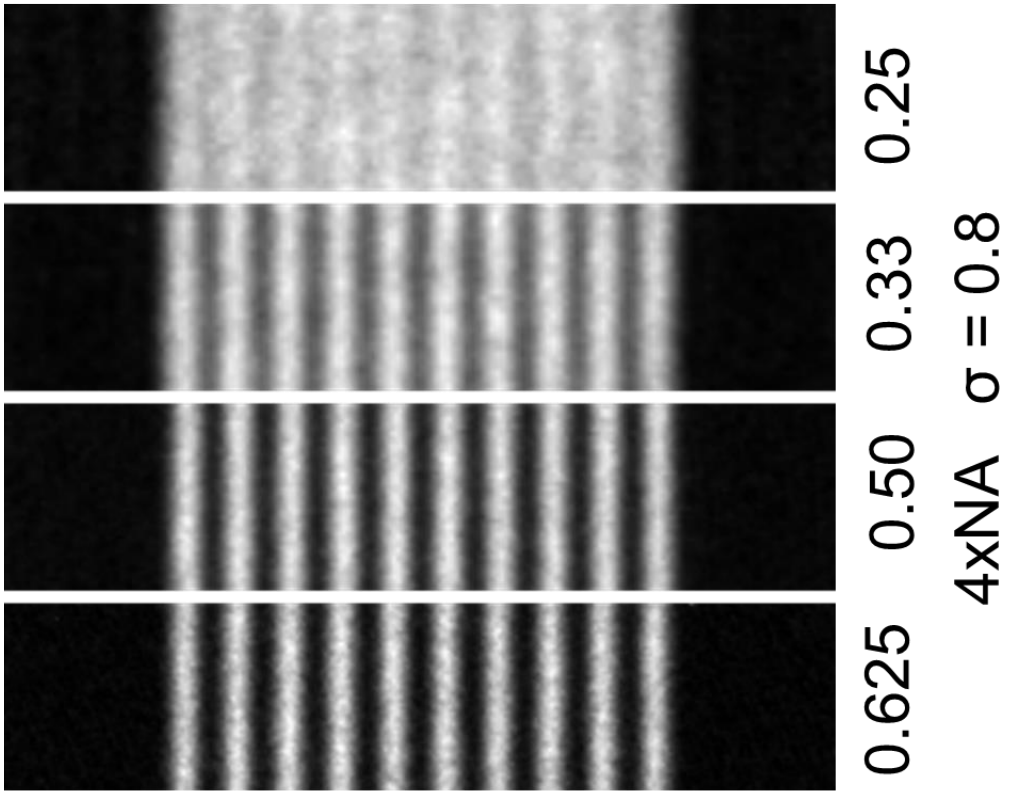
SHARP

Freeform source capabilities



Ken Goldberg

0.625 effective NA demonstrated



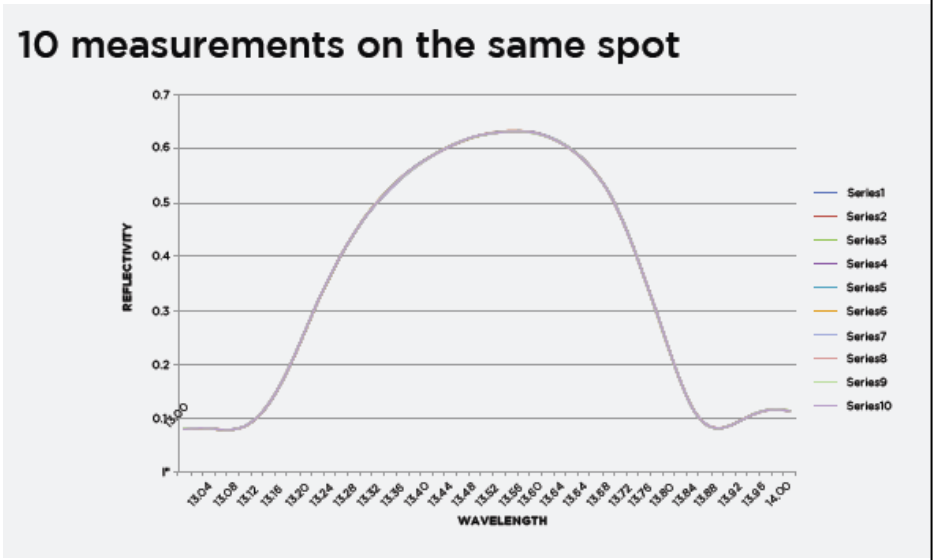
FOURTH GENERATION EUV REFLECTOMETER

Rupert C.C. Perera
EUV Tech, Martinez, CA 94553 / www.euvtech.com / E-mail: rupert.perera@euvtech.com

euvtech

LOCATION	PEAK REFLECTIVITY (ABS)	PEAK REFLECTIVITY PRECISION	PEAK WAVELENGTH (NM)	PEAK WAVELENGTH PRECISION (NM)
Absorber	1.49%	3σ = 0.009%	13.553	3σ = 0.0009%
Pattern Area	25.79%	3σ = 0.05%	13.556	3σ = 0.0009%
Black Border	0.035%	3σ = 0.0032%	N/A	N/A
2x2mm High Reflectivity Window	61.25%	3σ = 0.15%	13.553	3σ = 0.0006%
4x4mm High Reflectivity Window	61.25%	3σ = 0.10%	13.553	3σ = 0.0006%

10 measurements on the same spot

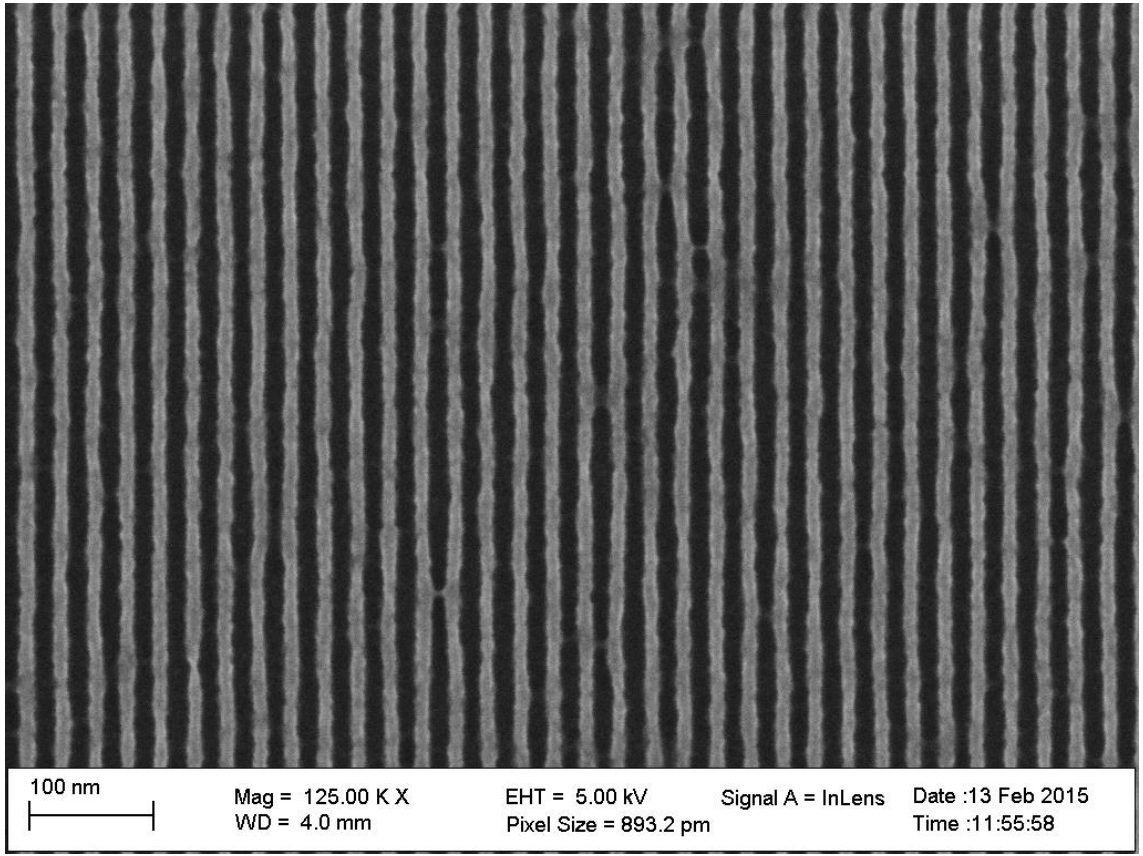


Resist

- Inpria- Inorganic resists
- Oregon State- Inorganic resists (1:40 Wed)
- Cornell- Nanoparticle resists
- CNSE- Metal organic resists
- Berkeley Lab- Rad chemistry fundamentals, Alt materials, Micro-exposure tools
- Georgia tech- Negative resists
- IBM- Alt. resist materials

13-nm patterning achieved in non-CA resist

BERKELEY LAB
B-MET



60 mJ/cm^2

LWR = 3.1 nm

inpria

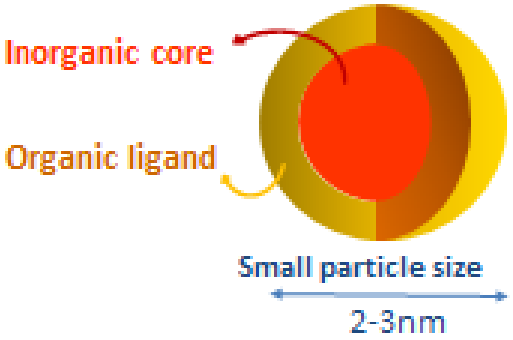
Oxide Nanoparticle EUV (ONE) Resists

Metal oxide cores: hafnium oxide, zirconium oxide, titanium oxide, etc.

- Reasonable EUV radiation absorbance
- High molecule density.

Carboxylic acid ligands: methacrylic acid, benzoic acid, etc.

- Enhance solubility in deposition solvents
- Lead to the solubility switch
- Affect sensitivity



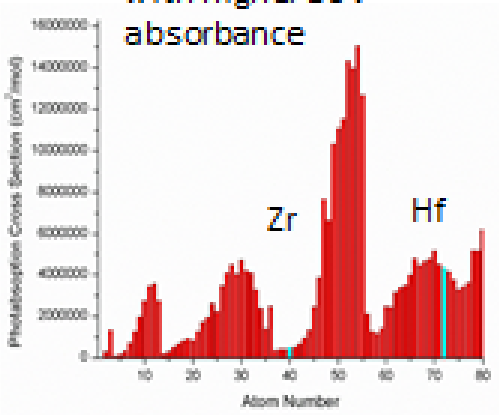
Decreasing speed

Ligands tested

1. DMA
2. Methacrylic acid
3. Isobutyric acid
4. Benzoic acid
5. Toluic acid
6. Nitrobenzoic acid

√ √ √ √ EUV tested

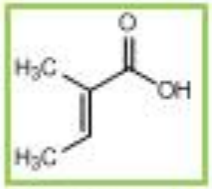
Incorporating metals with higher EUV absorbance



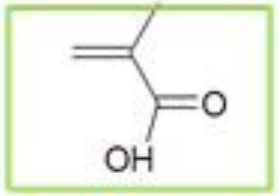
Cornell University

Selection of Hybrid Nanoparticles

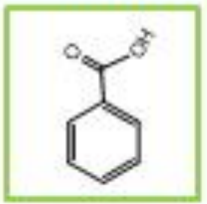
Hybrid Nanoparticles



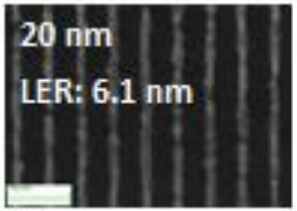
DMA--- Dimethylacrylic acid

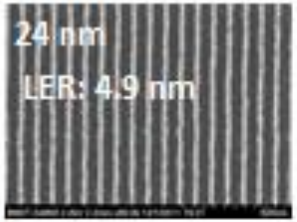


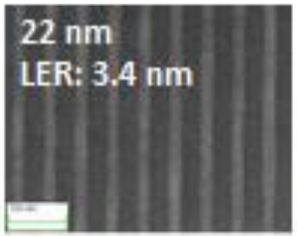
MAA--- Methacrylic acid



BA---Benzoic Acid







EUV Sensitivity

2.2 mJ/cm^2

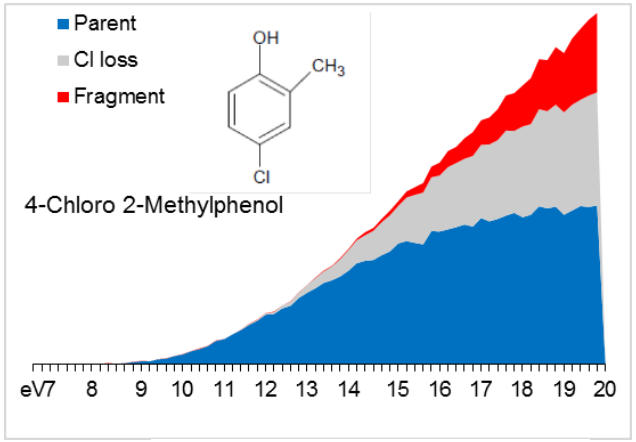
4.2 mJ/cm^2

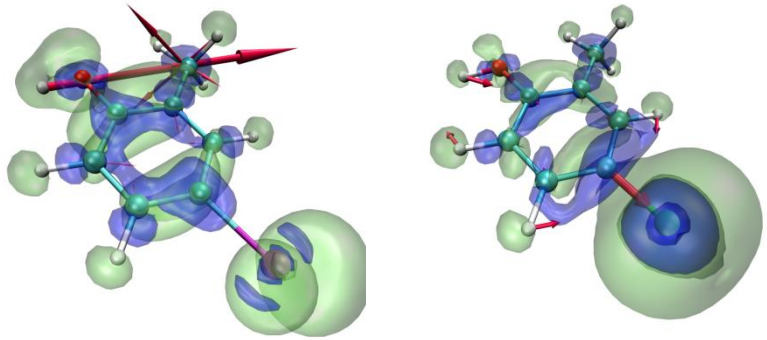
15 mJ/cm^2

SEMATECH

EUV radiation chemistry fundamentals

- Probe secondary electrons and mass spectra from EUV activated molecular beam
- Develop ab-initio models for radiation chemistry
- VMI tool built
- Initial measurements and modeling underway

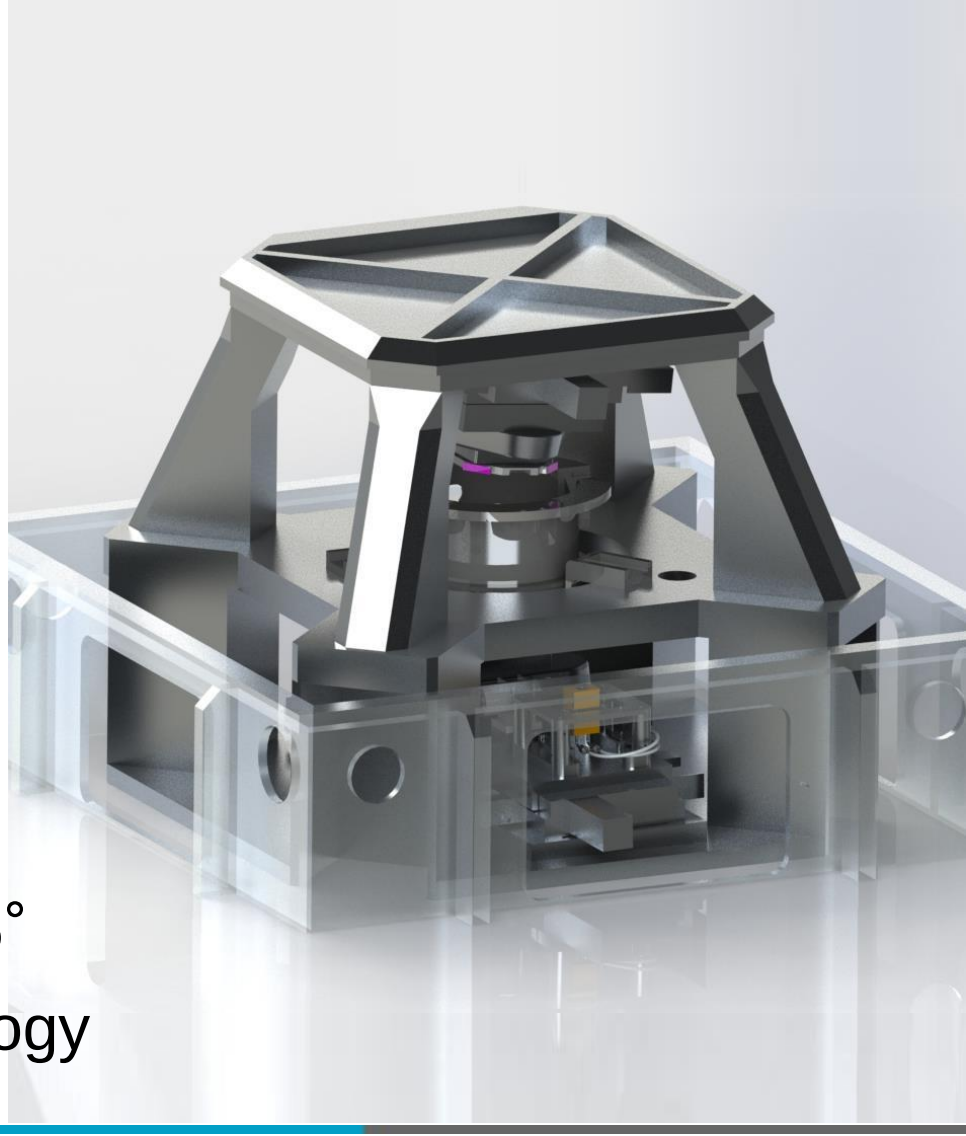




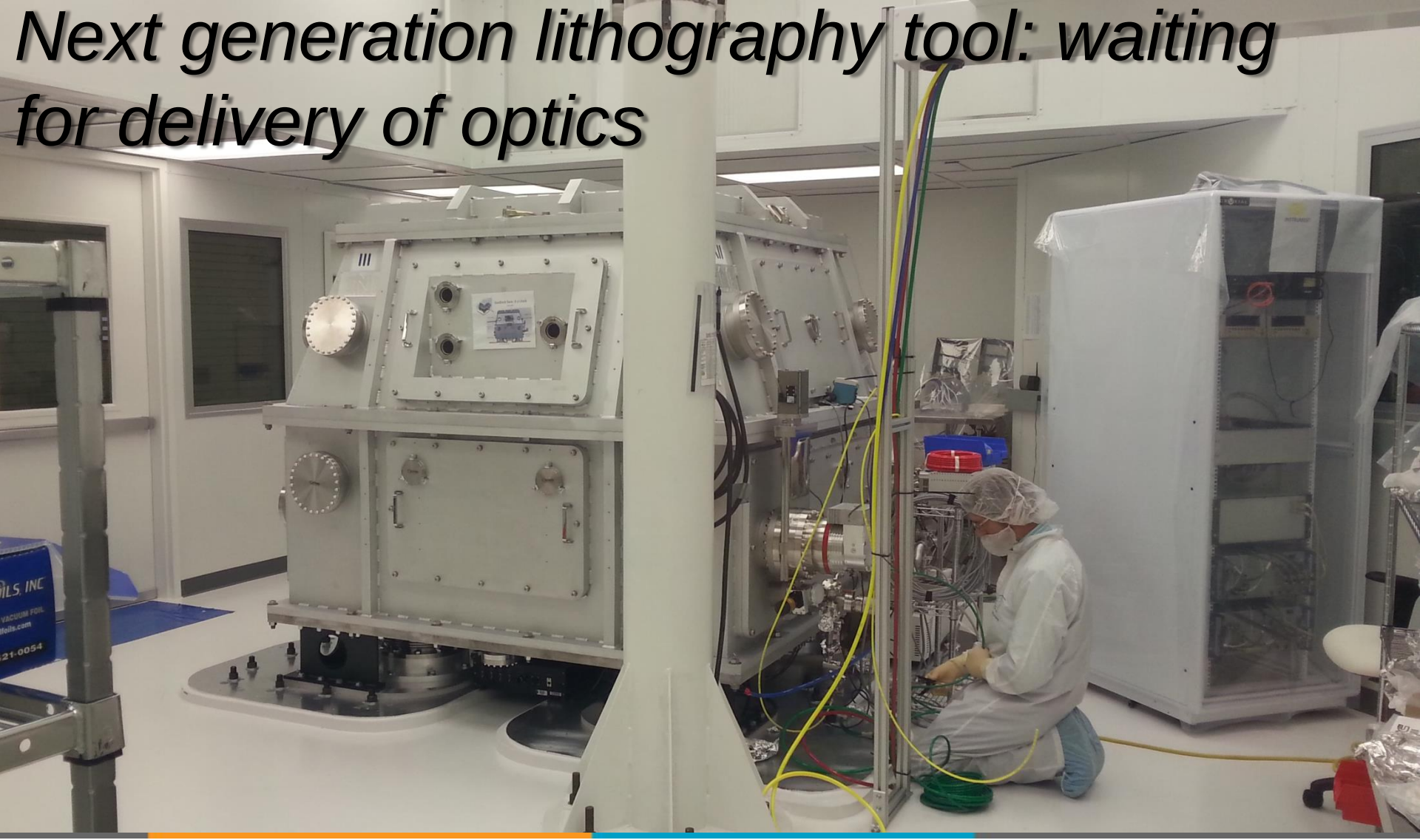
4-Chloro 2-Methylphenol

MET5

- NA = 0.5
- Magnification = 5x
- Resolution limit = 8 nm
- Programmable pupil fill
- Field of view = 200x30 μm
- Mask angle of incidence = 6°
- Integrated wavefront metrology



Next generation lithography tool: waiting for delivery of optics



Thank You